

The very fast evolution of Sakurai's object

G. C. Van de Steene¹ and P. A. M. van Hoof¹ and S. Kimeswenger²
and A. A. Zijlstra³ and A. Avison³ and L. Guzman-Ramirez⁴ and M.
Hajduk⁵ and F. Herwig⁶

¹Royal Observatory of Belgium, Astronomy & Astrophysics, Ringlaan 3, Brussels, Belgium
email: g.vandesteene@oma.be

²Universidad Catlica del Norte, Antofagasta, Chile

³Jodrell Bank Centre for Astrophysics, Manchester, UK

⁴Sterrewacht, Universiteit Leiden, The Netherlands

⁵Nicolaus Copernicus Astronomical Center, Torun, Poland

⁶University of Victoria, Victoria, Canada

Abstract. V4334 Sgr (a.k.a. Sakurai's object) is the central star of an old planetary nebula that underwent a very late thermal pulse a few years before its discovery in 1996. We have been monitoring the evolution of the optical emission line spectrum since 2001. The goal is to improve the evolutionary models by constraining them with the temporal evolution of the central star temperature. In addition the high resolution spectral observations obtained by X-shooter and ALMA show the temporal evolution of the different morphological components.

Keywords. planetary nebulae: individual (V4334 Sgr), evolution, Stars: AGB and post-AGB, circumstellar matter

1. Introduction

V4334 Sgr (a.k.a. Sakurai's object) is the central star of an old planetary nebula (PN) that underwent a very late thermal pulse (VLTP) a few years before its discovery in 1996 (Nakano et al. 1996). During the VLTP it ingested its remaining hydrogen rich envelope into the helium burning shell and ejected the processed material shortly afterwards to form a new, hydrogen deficient nebula inside the old PN. The star brightened considerably to become a very cool (born-again) AGB star with a spectrum resembling a carbon star. After a few years, dust formation started in the new ejecta and the central star became highly obscured, similar to R CrB stars. Emission lines were discovered: first He I 1083 nm in 1998 (Eyres et al. 1999), later in 2001 also optical forbidden lines from neutral and singly ionized nitrogen, oxygen and sulfur (Kerber et al. 2002). Sakurai baffled the scientific community with its very fast evolution, much faster than pre-discovery models predicted. The current models (Lawlor & MacDonald 2003, Herwig et al. 2011, Herwig et al. 2014, Miller Bertolami et al. 2006) can be improved by constraining them with the temporal evolution of the central star temperature.

2. Observations and results

2.1. Optical monitoring

We have been monitoring the evolution of the optical emission line spectrum since 2001 using spectra obtained with FORS at the ESO-VLT (Fig. 1). The goal of this monitoring program is to derive the stellar temperature as a function of time (van Hoof et al. 2007,

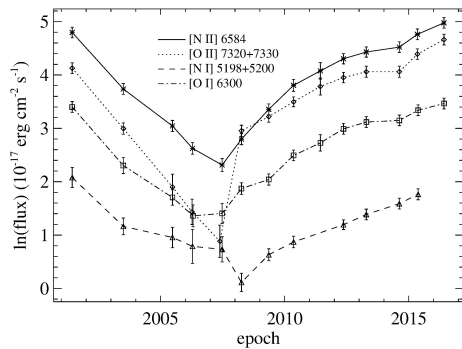


Figure 1. Evolution of emission line fluxes since 2001.

Some have tentatively been identified as electronic transitions of CN. At least some of these newly emerging lines are formed very close to the central star, possibly in the disk. In the PV diagram of [N II] 658.3 nm, obtained with X-shooter, we see that the red- and blue-shifted emission come from different regions that are spatially shifted w.r.t. the continuum. This emission line, as well as other optical forbidden lines, originate in the bipolar lobes seen by Hinkle & Joyce (2014).

2.2. ALMA Observations

The continuum emission is unresolved which indicates that all the dust is in the disk. In the ALMA spectra we detect CO, CN, HC₃N, as well as ¹³C isotopologues of these species. The CO and HC₃N (+isotopologues) emission is unresolved, coincides with the position of the central star, and most likely comes from the disk (Fig. 2). The CN and ¹³CN emission is spatially resolved and coincides with the bipolar lobes seen by Hinkle & Joyce (2014) (Fig. 2). CN could be formed via shock-induced dissociation of HCN in the lobes.

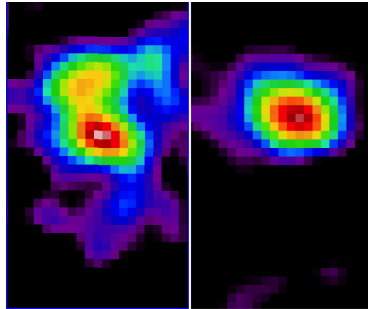


Figure 2. CN (left) and CO emission (right) detected by ALMA in 2015.

References

- Chesneau, O., Clayton, G. C., Lykou, F., et al., 2009, *A&A*, 493, L17
 Eyres, S. P. S., Smalley, B., Geballe, T. R., et al., 1999, *MNRAS*, 307, L11
 Hajduk, M., Zijlstra, A. A., Herwig, F., et al., 2005, *Science*, 308, 231
 Herwig, F., Pignatari, M., Woodward, P. R., et al., 2011, *ApJ*, 727, 89
 Herwig, F., Woodward, P. R., Lin, P.-H., Knox, M., Fryer, C., 2014, *ApJ*, 792, L3
 Hinkle, K. H., & Joyce, R. R., 2014, *ApJ*, 785, 146
 Kerber, F., Pirzkal, N., De Marco, O., et al., 2002, *ApJ*, 581, L39
 Lawlor, T. M., & MacDonald, J., 2003, *ApJ*, 583, 913
 Miller Bertolami, M. M., Althaus, L. G., Serenelli, A. M., Panei, J. A., 2006, *A&A*, 449, 313
 Nakano, S., Sakurai, Y., Hazen, M., et al., 1996, *IAU Circ.*, 6322, 1
 van Hoof, P. A. M., Hajduk, M., Zijlstra, A. A., et al., 2007, *A&A*, 471, L9
 van Hoof, P. A. M., Hajduk, M., Zijlstra, A. A., et al., 2008, *ASP Conf. Ser.*, vol. 391, 155